



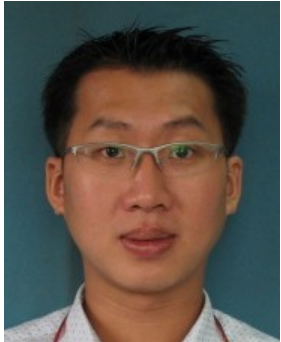
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Operating with a broken pinion teeth
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Presenter/Author bios



Vasanth Bhat is a Integrity Manager at Singapore Refining Company (A joint venture refinery between Chevron & Petro China). During his last 9 years with SRC, his main role has been to support all technical and asset management issues with regards to rotating machinery in the refinery. Prior to this, Mr. Vasanth had over 19 years of experience in various roles as consultant , Sales , Reliability & Maintenance engineer in organizations in India , Middle east and Singapore. Mr. Vasanth has a Masters Degree in Rotating Machinery from the University of Zaragoza (Spain) ;B.E. degree (Mechanical Engineering, 1989) from Manipal Institute of technology – India and is a certified Category IV Vibration specialist by Vibration Institute USA .



Keith Loh is a Reliability Manager at Singapore Refining Company (A joint venture refinery between Chevron & Petro China). Mr. Keith has over 10 years of experience in commissioning, maintenance and condition monitoring of rotating equipments in petroleum refinery . He has hands on experience in trouble shooting of turbo machineries, reciprocating compressors and centrifugal pumps. Prior to this, Mr. Keith worked as field engineer in gas turbines industry. Mr. Keith holds a Honors Degree in Mechanical Engineering from Nanyang Technological University, Singapore (2005).



Summary

There was a failure in the gear box of the main feed pump of the hydrocracker unit. As no spare was available, there was no immediate fix to the failure. A quick evaluation of the damage to the gear was done and an interim measure was taken to use back the old damaged pinion shaft.

A successful risk based repair and restoration plan developed jointly with OEM support, until the new spare gear set was made available. The paper highlights on the ways the risks were managed during this interim period and share the observations during this interim operation.



Hydrocracker Feed Pump Gear Box

As it would be in most cases the feed pump is a high speed barrel type multistage pump (10 stages) driven by a two pole motor (1250 HP) through a speed increasing API 613 gearbox at 6400 rpm.


The double helical gear and pinion combination gearbox built to API 613 standard has been in trouble free operation for over 20 years.

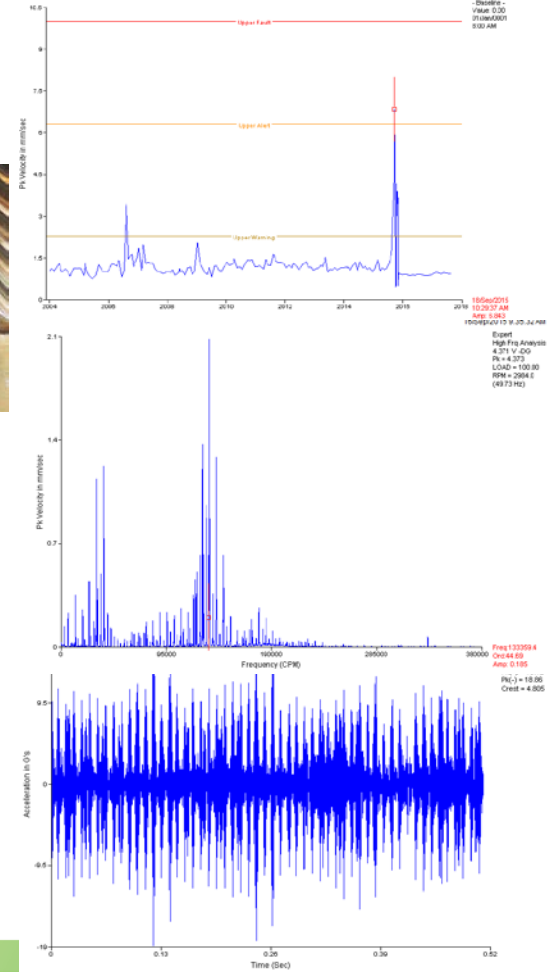
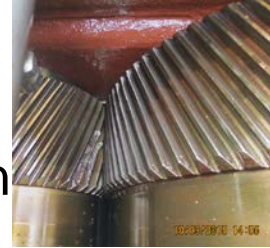
The original pump configuration was 1+1 .i.e. one unit in operation and the other unit on stand by mode.

Later due to capacity creep it was decided to put both the pumps in parallel operation. A loss of availability in one of the pumps results in 25% reduction in plant through put.



Failure Event

- Abnormal noise was observed in one of the pumps and appeared to be from the gearbox.
 - A significant increase in vibration was observed at the gearbox .
 - The spectrum showed up gear mesh with sidebands and multiple harmonics pattern similar to looseness.
 - The time waveform showed multiple impacts indicating potential of broken tooth.
 - Pump was shutdown and gearbox was opened up for inspection. Found two teeth on the pinion broken. Pitting observed on other teeth.
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Findings

- The previous inspection history of the gearbox did not indicate any abnormality.
- Due to the edge loading on the gearbox teeth the pump side was inspected and found that the thrust float was abnormal.
- Further inspection revealed the thrust bearing was damaged.
- The shift in the pump shaft towards the gearbox caused the gearbox pinion to be misaligned ,resulting in the pinion teeth to break.
- The pump drive end mechanical seal was found with badly worn out face due to axial shift of the rotor.



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Seal Ring

Multiple chip off was found on the seal ring seal face.

Restoration Plan

- Based on the pump original criticality rating, it was considered not necessary to keep the complete gear set as an insurance spare.
- The bearings and seals of the train assembly were in spare.
- There were three options considered:
 - A. Get new spare gear set from OEM
 - B. Try to develop a gear set locally
 - C. Repair the pinion set
 - D. Use the higher speed gear set of the neighboring pump which had similar external dimensions but would result in the pump running at higher speed.



Evaluation of Options

Option A : The Gear Box OEM indicated 6 to 8 weeks as the shortest lead time for the gear internals to arrive.

This option had low risk but would result in significant loss, as unit will operate with only one pump resulting in close to 25% production capacity loss.

Option B : We could not find a local vendor to reengineer this gear set . Vendors wanted to send the failed gear sets to their center of excellence works outside Asia. This would end up taking almost the same time as the OEM lead time for new gear internals. Hence this option was not considered.

Option D : Was explored but as the pump speed would be higher, it would mean the parallel operation of the feed pumps would be further challenged. Also, we may need to carry out a quick rotor dynamic check to ensure that the feed pump will operate normally at higher speeds. The risk is further alleviated as no spare pump will be available for the one from which the gearbox will be shifted to this pump.



Evaluation of Options

Option C : The Gear Box OEM was contacted to evaluate the condition of the pinion and if there was any repair options available as a temporary measure. A detailed inspection of the pinion and the gear set was done and following action plan was developed :

- To carry out NDE for the complete gear set and identify all damage areas
- To dress the pinion to remove the damaged areas.
- To carry out 2 plane balancing of the pinion shaft and the gear post repair.
- To carry out a tooth contact check after assembly with bearings (replace if necessary)
- It was decided to install a temporary vibration monitoring system to have a continuous on line monitoring of gearbox shaft and gear box casing vibrations. The probe areas had to be dressed and ensured that the mechanical and electrical run outs are within the API 670 requirements.

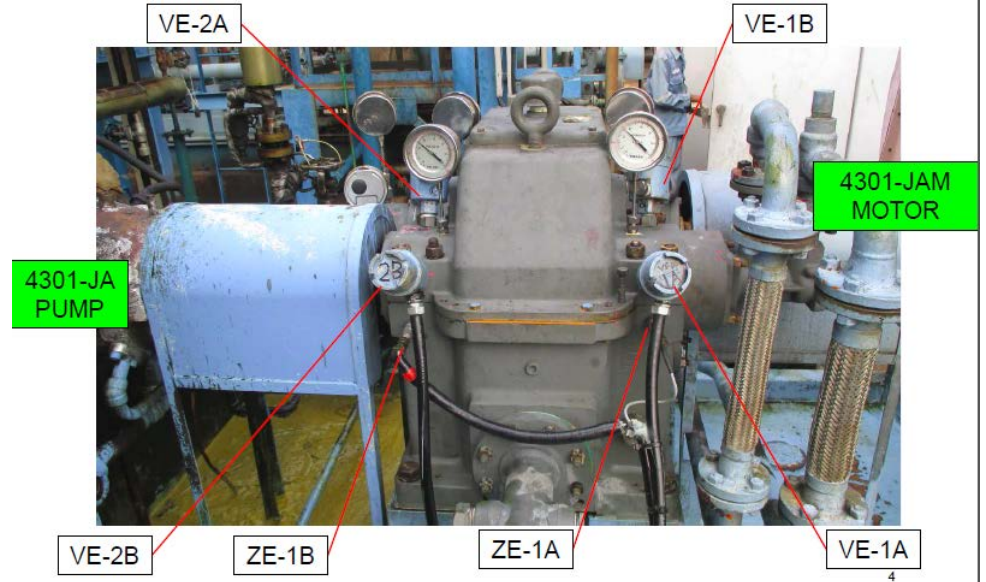
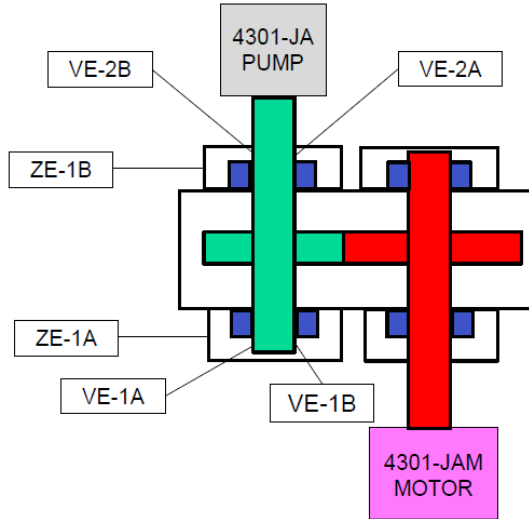


Repair Details

- After NDE, major length of the damaged teeth had to be dressed.
- Based on the removal of mass from the broken section, the amount of unbalance on the pinion rotor was high. Multiple areas were used to compensate for the unbalance mass so that the strength of the gear is not significantly compromised and would not become areas of major stress concentration.
- Rotors were balanced close to G1 and bearing clearances maintained in the optimum range.
- As a spare vibration monitor was available it was installed on a temporary basis with non contact probes installed at both ends of the pinion shaft with casing vibration measured in radial directions. The alarm from the monitor was connected to a DCS alarm so that the operator would get an immediate information if there was any abnormality.



Vibration Monitoring Set up



Post Repair Run

- An initial run was done without connecting to the pump and found the gearbox vibrations and noise were well within the acceptable limit.
- The pump was coupled and the train was gradually loaded up . The gear box noise levels were slightly elevated but the vibrations were well within the limits
- The pump was run back in normal operation within 20 days after the failure.
- The pump was operated with the temporary repair for another 3 weeks before the spare gear box was received.
- The complete gearbox was swapped but no major damage observed on the pinion shaft when removed.



Implications of this Failure

- Case studies with damaged tooth on bull gear and successful temporary operations have been reported. This is an unique example of a pinion with two broken teeth which has higher loading compared to bull gear.
- The case study does not go into the detail root cause of the pump bearing failure which resulted in the pinion failure. The two major causes were found to be gaps in the Preventive maintenance tasks and pump start up procedure, which were addressed before the pump start up.
- A complete RCA, Critical recommendation implementation and a stringent MOC process was adopted to ensure the safe operation of the pump.
- A great team work between multiple agencies, internal and external to the organization were key elements of the success.



Lessons Learnt

1. Importance of providing on line monitoring and protection for critical feed pumps to minimize failure & damage.
2. Regular monitoring of insurance spares and review is done on the critical spares especially when operational criticality changes are made.
3. Working with the equipment OEM, we can arrive at feasible repair options . With combined reviews on inspections of repair and post monitoring, significant reduction in equipment restoration times and successful operation is possible.

